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SKYLAB NUTRITION EXPERIMENTS

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Introduction

It is the primary purpose of next year's Skylab missions to obtain precise information on the long-term effects of weightless flight upon physiological and biochemical functioning. Unlike any previous U.S. space mission, Skylab is designed primarily to gather medical information. For the first time, space medicine specialists will have the opportunity to explore in depth the subtle changes which they have noticed emerging on the shorter duration flights of the Gemini and Apollo series.

A nutritional study figures prominently among the medical investigations to be pursued intensively during the Skylab program. Its primary purpose is to assess the effects of space flight on nutrition and musculoskeletal function. It will consist of a metabolic balance study designed to quantitate the effects of space flight on the rate of gain or loss of key chemical constituents from the body. In parallel with this study, an exhaustive endocrinological investigation will be conducted to probe those changes in control function which accompany or precipitate changes in body composition and fluid and electrolyte metabolism. The combination of separate investigations designed to study these factors has been assigned to flight by NASA as the M-070 experiment series entitled "Nutrition and Musculoskeletal Function."

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Purpose

The Skylab nutrition experiments are designed to enable investigators to acquire kinetic data on changes in body chemistry as a function of time of exposure to weightless flight. In this manner, they differ qualitatively from most previous studies in that the latter depended largely on pre- and postflight measurements only. It is pertinent, however, to note that the three crewmembers who will embark on the final lunar mission in December will also be subjected to a fairly rigorous in-flight balance study. They will collect and return samples of metabolic excreta throughout flight and will be consuming a precisely controlled intake. This flight is, in a sense, a dramatic preview of Skylab.

Alterations in calcium metabolism continue to be one of the major threats to the health of astronauts during long-term exposure to weightless flight.[1,2] Studies with immobilized subjects would indicate that the clinical disorders most likely to be encountered during prolonged space flight are primarily a consequence of an imbalance between bone formation and resorption. Under these conditions, there occurs loss of skeletal mass leading to osteoporosis, hypercalcemia, hypercalcuria, and sometimes nephroliphiasis.[3,4]

Immobilized or inactive bed rest has long been regarded as the nearest simulation to weightlessness for long-term measurements. Long before space flights were planned, studies by Dietrick, Whedon and Shorr[4] of immobilization of four healthy young men demonstrated clearly that marked increases in urinary calcium to approximately double controlled levels occurred in 5 weeks. The calcium balances were significantly negative as were balances in nitrogen and phosphorus.

With the advent of space flight, additional studies have been reported concerning the effects of simulated weightlessness on skeletal metabolism. Graveline, et. al.,[5] reported no increase in urinary calcium excretion in their study of one subject during one week of almost continuous water immersion. Although this is regarded as a realistic simulation of the weightless condition, the study was probably too brief to permit any conclusion with respect to an effect on calcium excretion. On the other hand, Birkhead, et. al.,[6] studying four subjects during 42 days of bed rest and 18 days of controlled activity preceding and following the bed rest phase demonstrated the development of sustained increases in urinary calcium excretion. Mack, et. al.,[7] have shown similar results although of lesser magnitude, and in addition have demonstrated changes in bone density of the os calcis during bed rest.

Lynch, _et_. _al_.,[8] have investigated the role of a reduced atmospheric pressure in modifying the effects of bed rest. In 22 healthy men, bed rest for 4 weeks at ground level pressure resulted in expected increases in urinary and fecal calcium and in urinary nitrogen, phosphorus, sodium, and chloride. In similar metabolic studies carried out with another 22 subjects at bed rest at simulated altitudes of 10,000 and 12,000 feet, urinary losses of calcium were significantly less as altitude increased. Urinary losses of phosphorus, nitrogen, sodium, and chloride were less at a 12,000 foot level as compared with the bed rest studies at ground level.

In the flight of Gemini VII in 1965, a complete metabolic balance study of two astronauts was conducted during a 10 day preflight control phase, 14 days of orbital space flight, and 4 days of postflight recovery.[9] Considerable individual variability was demonstrated in all experimental indices measured. In one man, significant increases in urinary calcium occurred during the second week of flight, and persisted during the recovery phase; calcium balance became less positive in-flight in both subjects. Urinary phosphate excretion increased substantially in-flight in both subjects despite reduction in phosphate intake. Urinary nitrogen and sulfide excretion decreased in-flight but less than would be expected from the reduction in intake. These limited data available from in-flight studies tend to support the use of immobilization as a terrestrial model for alterations in calcium metabolism during space flight. In periods of bed rest lasting from 30 to 36 weeks, calcium losses from the skeleton averaged 0.5 percent of total body calcium per month.[10] Tenfold greater rates of loss from the central portion of the calcaneus were observed by x-ray transmission scanning.[11]

Mineral loss during bed rest is probably due to a reduction in the forces which are being applied to the skeleton during normal activity. These forces would also be absent in the hypogravic environment of space flight. Loss of bone mass during space flight is, therefore, expected on theoretical grounds,[12] and for these reasons it is considered very important to quantitate these losses and later find methods of preventing them.

Procedures

It was to obtain definitive information on the rate of occurrence of these losses in-flight that the nutrition experiments were designed. The experiment consists of a complete input and output measurement on all Skylab astronauts commencing 21 days preflight, continuing throughout the in-flight phase, and for an 18 day period postflight. All nutrient and water intake is precisely measured. All fecal material and urine samples are returned to earth for analysis, and samples of blood are taken preflight, in-flight, and postflight.

The Skylab nutrition experiments will be the most rigorous metabolic studies ever conducted in manned space flight, and are indeed the prime objectives of the mission. However, a secondary objective of Skylab is to test those environmental conditions thought to be necessary to optimize psychological performance of the crews.

As a design goal, the Skylab spacecraft is to be made so pleasant a living and working environment that the crew will be reluctant to leave it. Foremost among the conditions of life known to influence behavior is the type and variety of the food system. Two conflicting goals were, therefore, presented to the spacecraft designers. One was to design equipment to support an intensive metabolic investigation, and the other was to design equipment that was to make the spacecraft as habitable as the technology permitted.

Food System

The food system to be employed in Skylab is basically composed of 72 different food items. These items are packed in aluminum cans and contain a variety of frozen, thermostabilized, dehydrated and compressed foods. A facility exists on Skylab to heat some foods prior to consumption and to maintain others in a refrigerated state.

The energy requirements of each astronaut are estimated on the basis of his age and body weight, and are adjusted for some known effects of weightless flight. Taken into consideration at this point are the activity schedules anticipated for flight and data previously acquired on in-flight oxygen consumption and pulse rates. Individualized menus are formulated and offered to the crews for 6 day feeding studies during which the crews are asked to exercise in their customary manner. After several iterations of this testing program during which crew weights are carefully monitored, menus are finalized.

A number of nutrients are controlled within rigid day-to-day tolerances as indicated on Table 1.

Table 1

Nutrient	Intake Range	Tolerance
Calcium	750 - 850 mg	$\pm$ 16 mg
Protein	90 - 125 g	$\pm$ 10 g
Phosphorus	1500 - 1700 mg	$\pm$120 mg
Sodium	3000 - 6000 mg	$\pm$500 mg
Magnesium	300 - 400 mg	$\pm$100 mg
Potassium (at least 3945 mg)		

Menus are designed according to 6 day cycles. The menus contain a core set of foods which provide the required levels of nitrogen, calcium, phosphorus, magnesium, potassium, and sodium. This core diet is approximately 300 kcals less than the caloric requirement established at 1 g. All additional calories are provided by food items which are low enough in controllable elements so as not to perturb the prescribed intake ranges. The latter are termed caloric adjustment items.

The crew will be encouraged to consume completely their nominal menu. A system of negative reporting will be employed such that the crew will report at the end of each day any deviation from the nominal menu. The only admissible deviations are the incomplete consumption or omission of an item on the nominal menu, the use of an off/nominal rehydration quantity or the consumption of a caloric adjustment item.

In order to maintain controlled intakes of calcium, phosphorus, magnesium, sodium, and potassium, in conjunction with these possible deviations, the crewmembers are also supplied with a series of mineral supplements by which the intake of any of these elements can be adjusted independently of the others. The mineral supplements are listed in Table 2.

Table 2

Supplements	Controllable Elements
Calcium Lactate	32 mg Calcium
Orthophosphate	110 mg Phosphorus
Magnesium Lactate	25 mg Magnesium
Sodium Chloride	197 mg Sodium
Potassium Gluconate	195 mg Potassium

A computer program has been designed to calculate mineral deficits from information transmitted to earth by the crew. The quantity of mineral supplements equivalent to these deficits is calculated in real-time and transmitted back to the crew.

Water System

Special attention has been given to the water consumed by the crew during the Skylab mission. The water system provides the capability to supply and dispense water for food and beverage preparation and drinking with an accuracy of $\pm$ 1 percent. A separate drink dispenser is provided for each crewman, and this dispenser contains a recording device for the amount of water dispensed. The water which the crewman ingests is essentially free of calcium, magnesium, phosphorus, nitrogen, potassium, or sodium.

In-flight Mass Measurement

In order to measure mass of such items as food residue and fecal material, a device is employed which measures and records the time associated with the period of a pendulum displaced a fixed distance through a spring supported restoring force. The masses to be measured are uniformly accelerated by this force and three periods of the pendulum are timed. Known masses are measured and a graph is developed which can be used to determine the mass of other objects. The minimal response to gravitational force of this device is eliminated in orbital flight by recalibration with the same known masses as used preflight. The difference in oscillating period which results from different masses is timed by interruption of a light train. A knife edge device attached to the oscillating system intermittently cuts the light train, triggering a timing circuit in the mass measurement device electronic subsystem. This time is converted and presented in millisecond units. The display provides a six digit readouts. A thermometer has been incorporated to sense and digitally display the temperature of a thermal pathway related to spring temperature. Correction values for temperature effects have been developed during 1 g calibration.

Two types of mass measurement device are placed onboard the spacecraft. One will accommodate small changes up to 1 kg and the other is large enough to measure the mass of an astronaut.

Waste Management System

The Skylab Waste Management System provides for the collection, processing, storage and disposal of feces, urine, and vomitus. It is designed to preclude mixing and cross-contamination of urine, feces, vomit and debris, between the crewmembers and also prevents cross-contamination in excess of 1 percent between samples from the same crewmember obtained on different days. The waste management system provides the capability for obtaining samples of the collected urine, feces, and vomitus, and retaining them for subsequent return to earth for analysis.

Urine is collected in a device called "Centrifugal Urine Separator Assembly" (CUSA). The CUSA permits urine from each micturation to be drawn into a centrifuge inlet line by entrained air from a downstream blower. The liquid is carried by centrifugal force to the outer diameter of a drum which is rotating at approximately 250 RPM. The rotating annulus of the urine impinges on a stationary pitot head through the outlet line to an external urine bladder. The system provides the capability to extract a representative sample of 122 ml from a homogeneous pool for freezing. The samples are frozen to below -2.5°F at the end of each 24 hour period. The urine collection unit determines the volume of each 24 hour void to an accuracy of $\pm$ 2 percent. A flushing capability is provided as a means of controlling cross-contamination between the 24 hour pooled urine collections for each user. Use of a flushing system limits the day-to-day cross-contamination between urine samples to less than one-percent of the volume collected each day.

The temperature of the urine being pooled does not exceed 59°F for more than an accumulated time of 3 hours during any 24 hour period.

A lithium chloride tracer is incorporated as an additional method to determine the volume of urine collected in each 24 hour urine pooling period. Lithium is added in the amount of 30 $\pm$ 0.3 mg into each pooling bag prior to flight. The primary mode of volume determination depends upon displacement of a pressure plate with a calibrated readout.

The fecal waste processor provides for vacuum drying of fecal and vomitus collections prior to long-term storage.

Blood Collection Equipment

Blood samples will be collected in-flight with the aid of a specially designed sampling device which will return approximately 11 ml of plasma in a frozen state for ground-based analysis.

Error Analysis

An error analysis has been conducted of the experiment in order to assess the effect of changes in design upon the ultimate sensitivity of the experiment. As currently conceived, it is expected that the experiment will be able to detect at the 2-Sigma level of confidence, changes in the body pool of calcium, at the end of the 56 day period of as little as 5 percent.

A mathematical model of the experiment has been formulated which will incorporate each component of the experiment, design, and operation which can contribute to error. This model is used to predict the effect of changes in any item of equipment or of any mode of operation.

Laboratory Analysis

All fecal, urine, and blood samples from Skylab will be returned to MSC for analysis. Extensive tests have been undertaken to establish a precise laboratory errors which are introduced in the analysis of these samples as well as errors arising from any degradation which may have occurred in the constituents of interest during prolonged storage in space and on the ground.

Pre- and Postflight Metabolic Control Periods

Metabolic control periods will be conducted for 21 days preflight, and for 18 days postflight. During these periods, the crew will consume Skylab flight foods which will be supplemented to a minor extent with fresh items to improve the acceptability of the flight diet. Complete collections will be made utilizing a biological specimen kit which is portable and which will enable the crewmembers to collect urine and fecal samples and preserve them in a frozen state until they are returned to the laboratory for analysis.

Baseline Studies

A variety of ground-based controlled studies have been conducted to determine the effect of various experimental variables other than weightlessness upon the parameters of interest.

The effect of long-term recumbency has been extensively studied in order to assess the effect of immobilization and hypogravia. The effect of varying intakes of protein, calcium, and magnesium on the parameters of interest have been investigated and the influence of different activity levels upon mineral balance have been studied.

These baseline studies culminated in a 56 day manned chamber study which has recently been completed at the Manned Spacecraft Center. This study was designated the Skylab Medical Experiments Altitude Test (SMEAT). SMEAT was a high fidelity mockup of Skylab in which three crewmembers were confined for 56 days and in which all the medical experiments including M-070 were performed in a manner as similar as possible to the way in which they will be performed in-flight. SMEAT, like Skylab, had an atmosphere consisting of 70 percent oxygen, and slightly less than 30 percent nitrogen. The partial pressure of carbon dioxide was maintained at about 2 percent, and the total ambient pressure was maintained at 5 PSI. Ambient temperature was maintained at about 70°F throughout the study with occasional excursions to 76°F. The due point was maintained between 45 and 55°F.

Due to a chamber slippage late in the program, the preflight metabolic control phase lasted for 28 days rather than the scheduled 21 days. The three astronauts successfully maintained controlled nutrient intakes throughout the study. Two of the astronauts showed no significant weight changes at the end of the study, while the third astronaut suffered a weight loss of approximately 17 pounds. This weight loss was associated with a change in body fat of approximately 4 pounds and a caloric deficit of about 600 calories per day. It proved not possible to correct this deficit with items stowed within the chamber without effecting the controlled nutrient intake levels. Care will have to be taken with the Skylab flights to more flexibly accommodate in-flight caloric needs and to take adequate consideration of very high levels of exercise activity.

Metabolic balance data plotted according to Reifenstein, et. al.,[13] for calcium and potassium for each of these three astronauts is depicted on the following slides. Conclusive statements on the metabolic consequences of the chamber exposure must await further analysis of this data. Dermal losses of calcium and potassium were ignored which may account in part for the overall positive balances.

Conclusion

The M-070 Skylab Nutrition Experiments are expected to give medical investigators precise information on a variety of biochemical changes occurring during exposure to space flight. Sufficient control data is being generated by baseline studies to differentiate those effects which are due to weightless flight and those which are due to other abnormal conditions which normally accompany space flight.

Some environmental conditions, however, remain uncontrollable. For instance, it is possible that fairly severe shifts in sleep cycles will be necessitated by factors associated with the nature of the Skylab orbit. The interaction of these factors with the physiological changes which the M-070 experiment is designed to detect will introduce some errors.

Nevertheless, these experiments will provide essential data on which decisions will be based on the qualification of man, first on the 56 day missions of the Skylab series, and then on missions of far longer duration.

M-070 and the other Skylab experiments taken together will eventually answer the question of whether man can endure indefinite exposure to weightless flight. If it appears that the physiological degradation that he suffers under these conditions is severe then a new era of space medicine will swiftly achieve maturity. This era will consist in the development of countermeasures to the deteriorative effects of weightless flight. Such countermeasures will be specific devices or procedures designed to preclude the occurrence of these physiological difficulties. It is in the development of these countermeasures that dietetic therapy will be exploited to the utmost.

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